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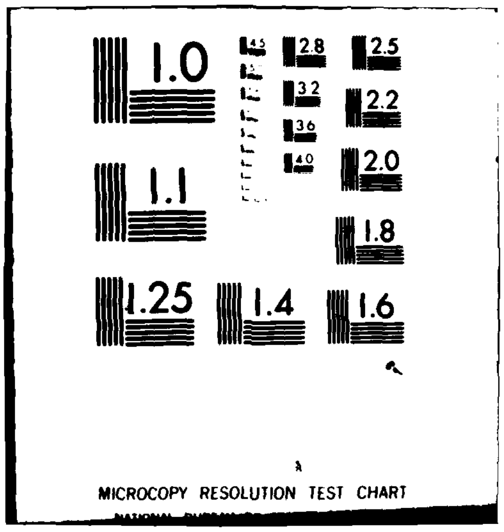
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IMPLICATIONS OF REALISTIC UTILITY FUNCTIONS FOR PLACEMENT USING APTITUDE-TREATMENT INTERACTION

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REPORT PREPARED UNDER OFFICE OF NAVAL RESEARCH
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When aptitude-treatment interaction (ATI) is used in placement decisions, it is generally assumed that a candidate should be placed in the treatment whose regression equation yields a higher predicted score. This can be justified using decision theory if utility functions are assumed linear and hence, unbounded. However, realistic utility functions ought to be bounded. Then the conventional placement rule is invalid. The optimum decisions depend on both the prediction equations and the utility functions. Therefore, the decision

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rule takes different forms in different situations. This is illustrated by assuming utilities to be proportional to normal distribution functions.

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Implications of Realistic Utility Functions for Placement Using Aptitude-Treatment Interaction

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Abstract

When aptitude-treatment interaction (ATI) is used in placement decisions, it is generally assumed that a candidate should be placed in the treatment whose regression equation yields a higher predicted score. This can be justified using decision theory if utility functions are assumed linear and hence, unbounded. However, realistic utility functions ought to be bounded. Then the conventional placement rule is generally invalid. The optimum decisions depend on both the prediction equations and the utility functions. Therefore, the decision rule takes different forms in different situations. This is illustrated by assuming utilities to be proportional to normal distribution functions.

When two or more "treatments" or training programs are available, one would like to place each candidate in that treatment which is likely to provide the most benefit for him/her. Three kinds of information are generally involved in such decisions--information about the candidate, about the treatments, and the utilities of possible outcomes. All candidates take a test measuring their aptitude for the training they are to receive. The outcome of training is measured with an achievement test. Available knowledge about the effect of a treatment is represented by a regression equation which predicts the achievement score from the aptitude score. Aptitude-treatment interaction (ATI) is said to be present if regression equations for the various treatments differ appreciably from one to another. Utility is a monotonic non-decreasing function of the achievement score, one for each treatment.

The importance of the utility function has received scant attention in the literature. It is often said that, of two treatments, the candidate should be placed in the one which yields a higher predicted score (e.g. Cooley & Lohnes, 1976, p. 74). When the concept of utility has been included in the analysis, the utility function has generally been assumed to be linear. Cronbach and Gleser (1965, p. 310) state this assumption explicitly. Cronbach and Snow (1977, p. 41) assume that utility and aptitude have a bivariate normal distribution. Since the usual regression model assumes the criterion and predictor to be bivariate normal, this implies that utility is a linear function of the achievement score.

As pointed out by Novick and Lindley (1978, p. 183), it is not realistic to assume that utility can increase or decrease without bound. This is particularly so when the purpose of the training is to enable students to pass a particular examination. It is then more reasonable to assume that utility is some function of the probability of passing, which is a bounded function of true score. Even in other contexts, one ought to take account of the fact that success in any enterprise depends on a number of different abilities, and therefore, no single score, however high, can have infinite value.

Consider two treatments A and B, with costs per person C_A and C_B. Let utility of extremely low scores be zero, and that of extremely high scores U_A and U_B in the two treatments. We shall see later that some conclusions depend only on these maximum values, irrespective of how utility varies with the achievement score. Hence, it is convenient to write the utility functions in a manner which clearly separates their limiting values and their functional forms. Let the utility of an achievement score Y be $U_A f_A(Y)$ at the end of treatment A, and $U_B f_B(Y)$ after treatment B. Both f_A and f_B are monotonic non-decreasing with range (0,1). The value of a skill depends on its future use, not on how it was acquired. Therefore, it is reasonable to assume that $U_A = U_B$ and $f_A \equiv f_B$ in which case the utility functions are identical. However, the decision-maker may feel that training improves not only academic achievement but also other qualities such as study habits. These additional benefits, and hence the utility function, may differ from one treatment to another. We shall call the functions "similar" if $f_A \equiv f_B$ but $U_A \neq U_B$. Without loss of

generality, we assume $C_A \geq C_B$. $(U_A - U_B)$ is the difference between maximum utilities. As the costlier treatment is not worth consideration unless it provides some extra benefit, we assume $U_A \geq U_B$.

We assume a normal model to predict achievement scores after treatment from aptitude scores. If the aptitude score is X, the distribution of Y after treatment A is normal with mean $\alpha_A + \beta_A X$ and variance σ_A^2. The corresponding regression parameters for treatment B are α_B, β_B, and σ_B^2. The two predicted distributions are used to calculate expected payoffs and the candidate is placed in the treatment which yields a higher value. Let the difference between expected payoffs be

$$\Delta P(x) = -C_A + U_A E[f_A(Y)|x) + C_B - U_B E[f_B(Y)|x].$$
$$= U_A E[f_A(Y)|x] - U_B E[f_B(Y)|x] - [C_A - C_B]$$

The preferred placement is in treatment A if $\Delta P(x)$ is positive and in B if it is negative.

The simple assumption of bounded utility functions has important consequences. $\Delta P(-\infty) = C_B - C_A$. Therefore, for persons with very low aptitude, the recommended placement is in the less expensive treatment which is B. Similarly, for a very high test score, ΔP approaches

$$\Delta P(\infty) = (U_A - U_B) - (C_A - C_B).$$

Therefore, if $U_A - U_B < C_A - C_B$, treatment B is preferable at very high aptitudes also. In particular, the inequality will hold if achievement score is the only outcome of interest and therefore $U_A = U_B$. Then candidates with very high and very low aptitudes are placed in

the same treatment <u>irrespective of the regression slopes</u>. This is contrary to what is usually taken for granted--that the treatment with higher slope is preferable at high aptitude and the other treatment at low aptitude. The more expensive treatment A is preferable at very high aptitude only if it provides enough additional benefits to make $U_A > U_B + (C_A - C_B)$, i.e., large enough to offset the additional cost.

In order to study $\Delta P(x)$ at finite values of X, we now assume that f_A and f_B are cumulative probability functions of normal distributions $N(\mu_A, \tau_A)$ and $N(\mu_B, \tau_B)$ respectively (Novick & Lindley, 1978). The use of a normal distribution function, combined with a normal regression model, yields a simple expression for expected values:

$$E[f_A(Y)|X = x) = \phi[(\alpha_A + \beta_A x - \mu_A)/ (\sigma_A^2 + \tau_A^2)^{\frac{1}{2}}]$$

where ϕ is the standard normal cumulative distribution function (op. cit., eqn. 2). Therefore, the condition for treatment A to be preferable can be written in terms of expected utilities:

$$\Delta U(x) = U_A\, \phi(a + bz) - U_B\, \phi(z) > C_A - C_B \tag{1a}$$

where

$$z = (\alpha_B + \beta_B\, x - \mu_B)/(\sigma_B^2 + \tau_B^2)^{\frac{1}{2}}\,, \tag{1b}$$

$$a = [(\alpha_A - \mu_A) - \beta_A(\alpha_B - \mu_B)/\beta_B]/ (\sigma_A^2 + \tau_A^2)^{\frac{1}{2}}\,, \tag{1c}$$

$$b = (\beta_A/\beta_B)\ [(\sigma_B^2 + \tau_B^2) / (\sigma_A^2 + \tau_A^2)]^{\frac{1}{2}}. \tag{1d}$$

The regions where one treatment is preferable to the other are separated by points where $\Delta U(x) = C_A - C_B$. The existence and locations of these points depend on four parameters. Of these, U_A/U_B and $(C_A - C_B)/U_B$ depend only on costs and on maximum utilties; a and b represent the combined effects of regression equations and utility functions. The function $\Delta U(x)$ can take different forms depending on the values of these parameters. Locations of its stationary points are the solutions (if any) of

$$(2\pi)^{\frac{1}{2}}\, d\Delta U/dz = bU_A \exp[-(a + bz)^2/2] - U_B \exp[-z^2/2] = 0$$

which is written more conveniently as

$$z^2(b^2 - 1) + 2abz + a^2 - 2 \log (bU_A/U_B) = 0 . \qquad (2)$$

$$(2\pi)^{\frac{1}{2}}\, d^2\Delta U/dz^2$$

$$= -b^2U_A(a + bz) \exp[-(a + bz)^2/2] + U_B\, z \exp [-z^2/2]$$

$$= U_B \exp(-z^2/2)[(1 - b^2)z - ab] \text{ at stationary points.} \qquad (3)$$

We can classify the various possible situations according to the number of stationary points of $\Delta U(x)$.

1. $\Delta U(x)$ increases monotonically if $a = 0$, $b = 1$. This is an uninteresting case. It will occur if the two treatments have similar utility functions and identical regression equations, or a highly coincidental combination of parameters.

   Another possibility is that solutions of Eqn.(2) are complex, i.e., that

$$a^2 < 2(1 - b^2) \log(bU_A/U_B). \qquad (4)$$

The dotted curve in Figure 1 shows an example, with $a = 0$, $b = .9$ and $U_A/U_B = 1.3$. If the difference between maximum utilities exceeds the difference between costs, i.e. $U_A - U_B > C_A - C_B$, there is a cut off score x^*. As in the conventional placement rule, treatment A is preferable if $x > x^*$ and B if $x < x^*$. However, it is interesting to note the conditions under which this occurs. Since $U_A \geq U_B + (C_A - C_B) > U_B$, inequality (4) can be satisfied only if $b < 1$. From eqn. (1d) it is clear that the condition $b < 1$ requires β_A to be not too large; in fact, if we assume similar utility functions ($\tau_A = \tau_B$) and equal residual variances, it requires that slope β_A should be <u>smaller</u> than β_B. This is contrary to the conventional rule that the treatment with steeper regression is preferable at high aptitude.

The two solutions of eqn.(2) are identical if the two sides of (4) happen to be equal. A little algebra shows that the solution is a point of inflexion, and hence $\Delta U(x)$ is monotonic non-decreasing.

2. Equation (2) becomes linear if $b = 1$ as, for example, when utility functions are similar and the regression equations differ only in their intercepts. Equation (3) shows that the stationary point is a maximum if $a > 0$ and a minimum if $a < 0$. The dashed curve in Figure 1 shows an example with $a = 1$ and $U_A/ U_B = 1.3$. If $C_A - C_B$ exceeds $U_A - U_B$ but is smaller than the maximum, treatment A is preferable in the

middle of the aptitude range while B is preferable at both very low and very high aptitudes. If $U_A - U_B > C_A - C_B$, there is a cut off score above which treatment A is preferable. The point to note is that the preferred treatment can depend on the aptitude score even when there is no aptitude-treatment interaction.

3. When eqn. (2) has two real and distinct solutions, $\Delta U(x)$ has a maximum and a minimum. This is illustrated by the solid curve in Figure 1 ($a = 0$, $b = 2$, $U_A/U_B = 1.3$). A similar curve will be obtained whenever utility functions are identical and regression for the more expensive treatment explains a larger proportion of the variance. With other values of the parameters, one or both of the extrema may lie between the asymptotes. Thus, the placement rule is highly sensitive to the parameters of the regression equations and the utility functions.

In summary, the usual placement rule (e.g. Cooley & Lohnes, 1976, p. 74) becomes invalid as soon as one makes two simple and realistic assumptions--the costs of the two treatments are unequal and the utility functions are bounded. Although the curves in Figure 1 were drawn using utility functions proportional to normal distribution functions (Novick & Lindley, 1978), it is unlikely that qualitatively different conclusions will be obtained with other functions. Placement rules based on ATI can be quite complicated, and depend not only on the regression equations (including residual variances), but also on costs

and utility functions. An even more important consideration is whether differential placement is worthwhile at all. According to Cronbach and Snow (1977, p. 42), "<u>It is the expected benefit to the extreme cases that justifies the practice of placement</u>" (italics in the original). It is precisely the extreme cases that are most affected by assuming utilities to be bounded rather than linear. With linear utilities and ATI, the difference between utilities expected from the two treatments increases with x without bound, which is why extreme cases are important. With bounded utilities, however, the difference has limits 0 and $U_A - U_B$ at low and high aptitudes. Then it becomes possible that it is better to use the less expensive treatment for everybody. While the theoretical importance of ATI is beyond question, its usefulness for placement cannot be judged until costs and benefits of the treatments are carefully quantified.

It should be noted that the treatment given here assumes a linear regression model with homoscedastic errors. Such a model implicitly assumes that the criterion variable can take any value from $-\infty$ to ∞. (This assumption is explicit when bivariate normality is assumed.) In such a case, boundedness of the utility function implies nonlinearity with vanishing slopes as $y \to \pm \infty$. Real-life variables, on the other hand, are always finite, and therefore any nonsingular utility function is bounded. Hence the requirement of "realism" does not impose any new restrictions, and it remains quite possible that the conventional placement rule is valid. A proper treatment of this question is complicated. Floor and ceiling effects are likely to make the regression nonlinear,

and error distributions heteroscedastic and skewed. Such complications are beyond the scope of this paper.

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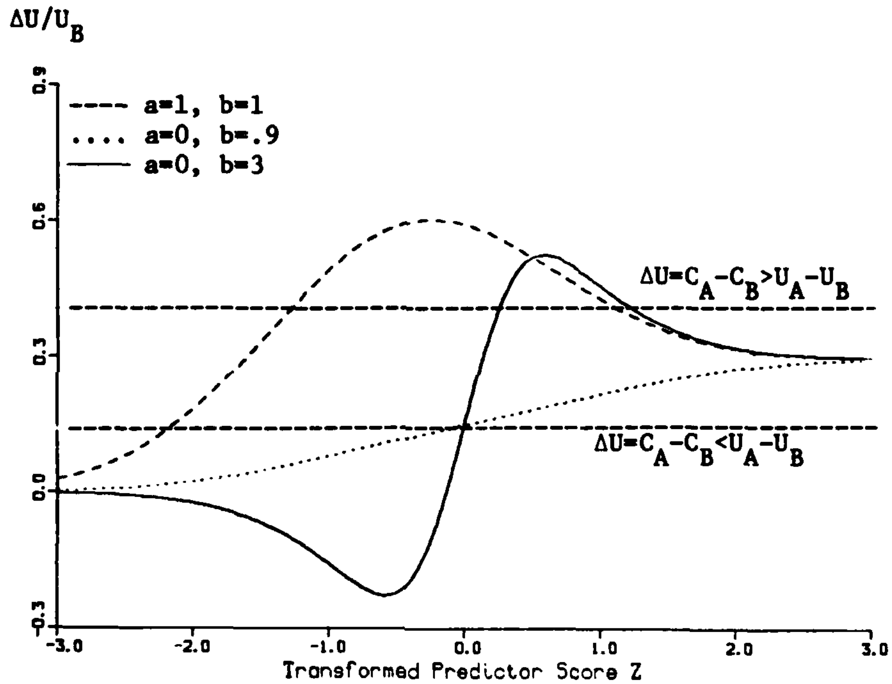
Figure 1

Possible Forms of $\Delta U(X)$ as a Function of Transformed Score Z ($U_A = 1.3\ U_B$)



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